



Laser Ablation of Metal Doped Polymers with CO₂ Laser

EOARD Grant FA8655-03-1-3061

Properties of Laser Ablation Products of Delrin with CO₂ Laser

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Report Documentation Page

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OUTLINE

- Who is DLR – Institute of Technical Physics (TP)?
- Lightcraft Research at TP
- Experimental Setup and Sample Types
- Results:
 - Flat samples in air
 - 3-D expansion
 - Vacuum
 - Comparison of different sample types
 - Tests with a light concentrating structure
- Scanning electron micrographs
- Conclusions and proposal



DLR - INSTITUTE OF TECHNICAL PHYSICS

German Aerospace Center



Astronautics

Traffic

Energy

Aeronautics

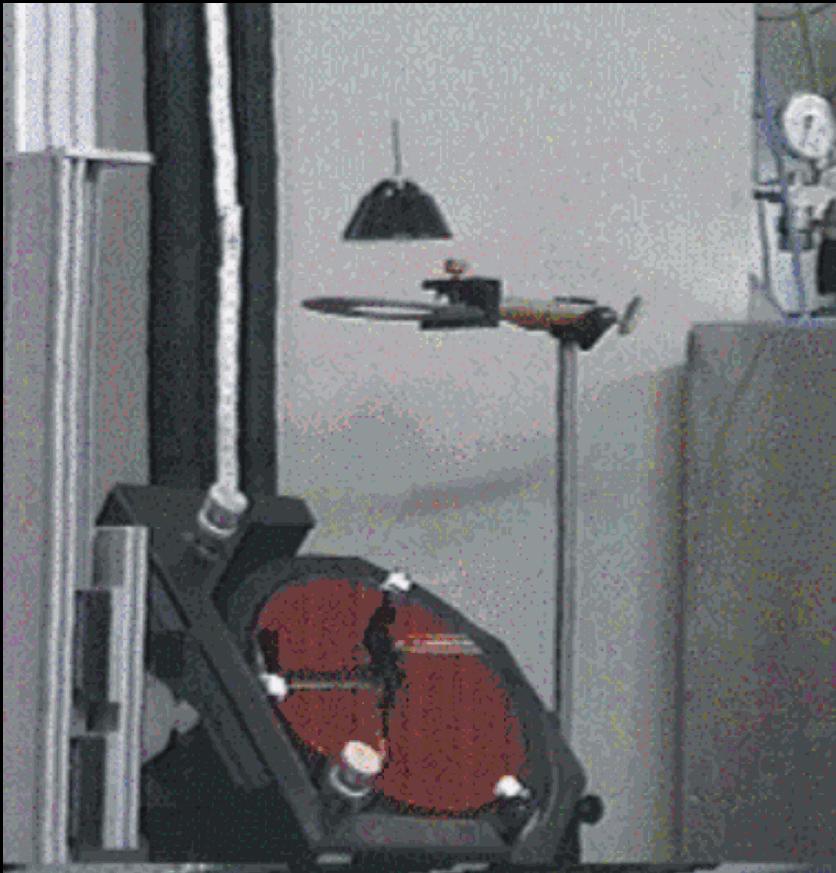
Institute of Technical Physics

HEL / COIL
SSL / NLO
Active opt. Systems

Studies & Concepts
Akquisition & Support



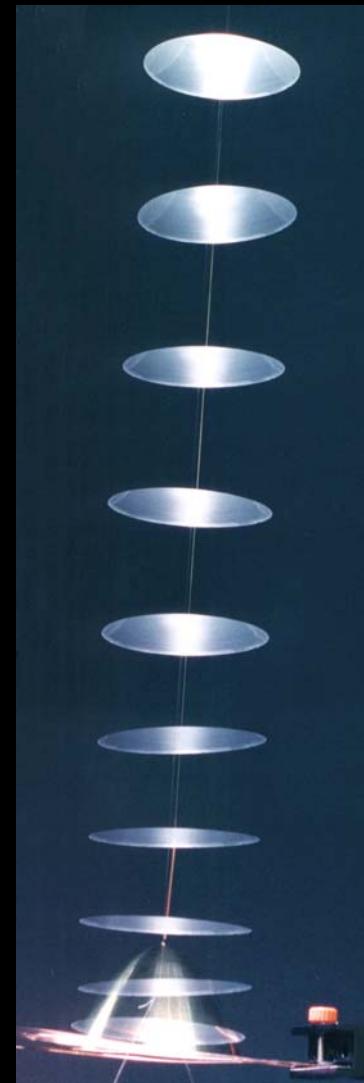
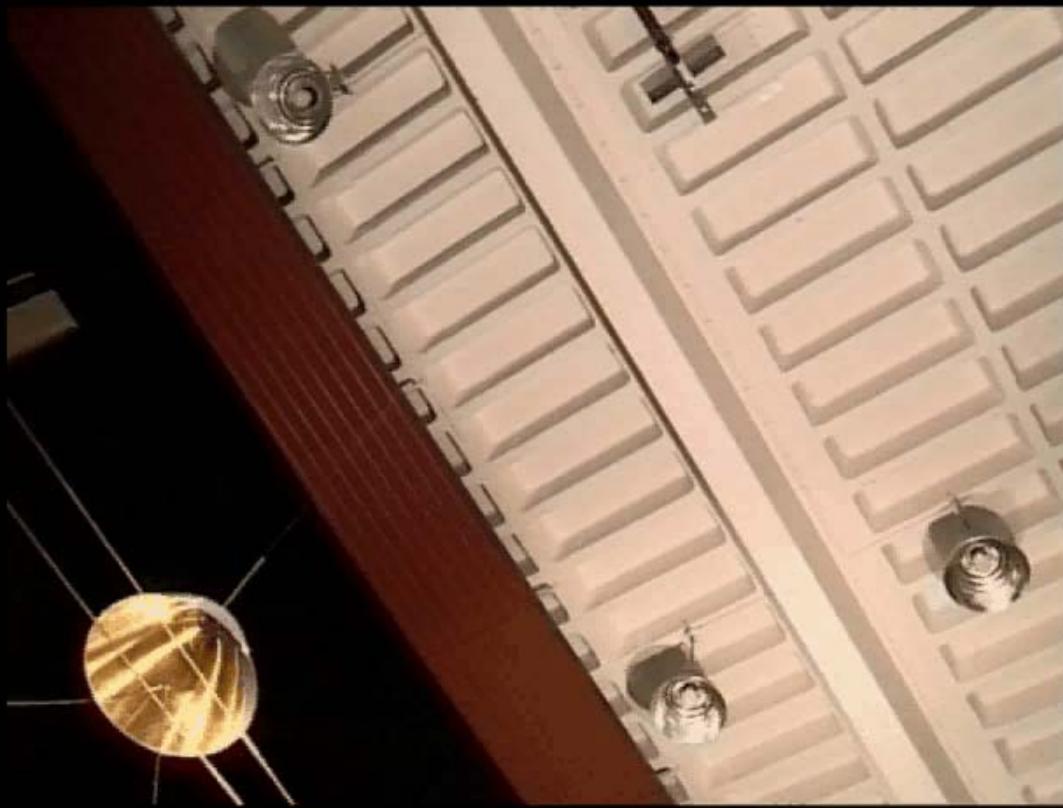
HOW IT ALL BEGAN ... (1998)



**Bicycle Headlight
Reflector**



LIGHTCRAFT FLIGHT





ACKNOWLEDGEMENT

Our special thanks go to

Dr. Franklin B. Mead Jr. and Dr. Carl W. Larson

(AFRL – Propulsion Directorate, Edwards AFB, CA)

Dr. Ingrid Wysong (EOARD - London)

(and all the others in the background)

for making our research and this visit possible.

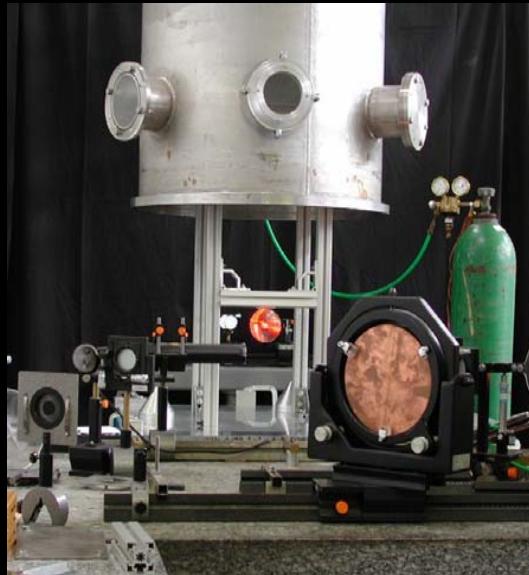


EXPERIMENTAL EQUIPMENT

Lightcraft



Vacuum Tank



E-beam sustained CO₂ Laser



Parabola with

Diameter 10 cm

Focal Distance 1 cm

Diameter 80 cm

Height 110 cm

Pulse Energy ... 420 J

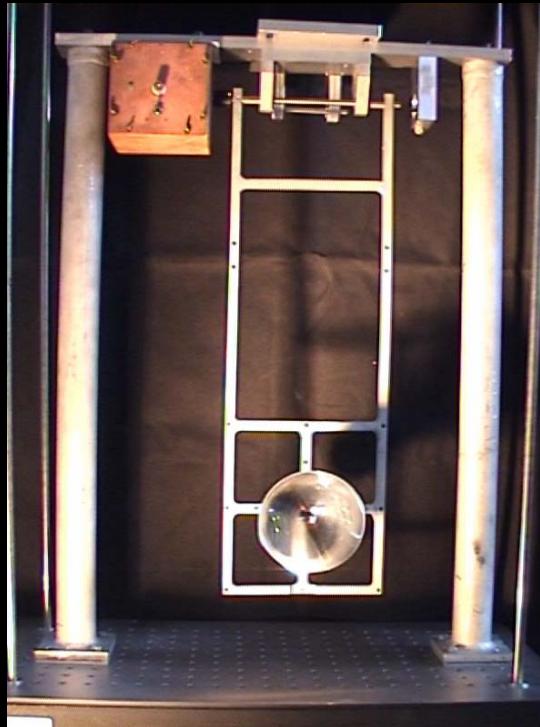
Repetition Rate ... 100 Hz

Wavelength 10.6 µm

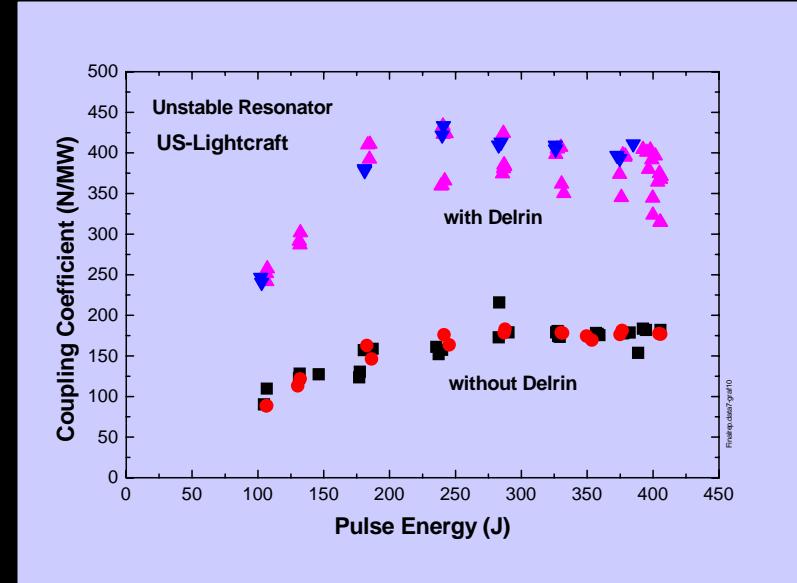
Pulse Length 3 ... 12 µs



INVESTIGATIONS FOR EOARD (Phase I – 2002)

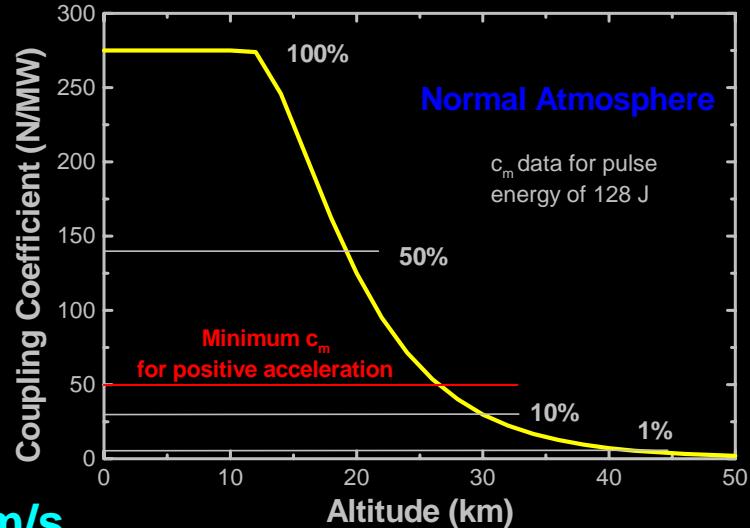
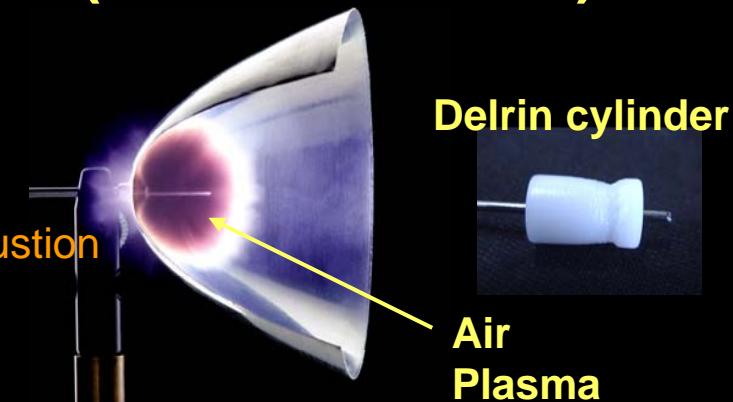
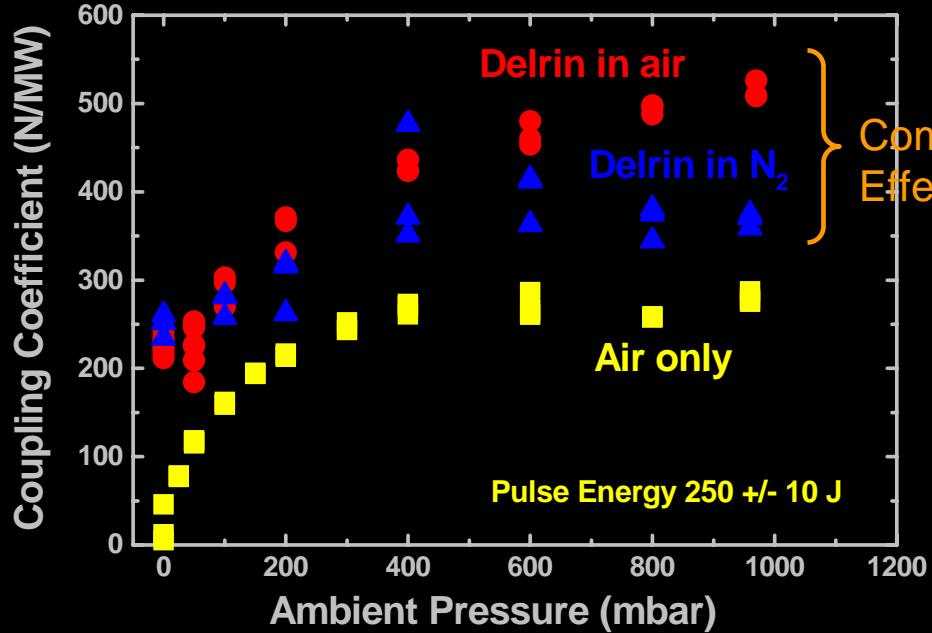


Comparison of measurement techniques and performance of US and German lightcraft





INVESTIGATIONS FOR EOARD (Phase II – 2003)

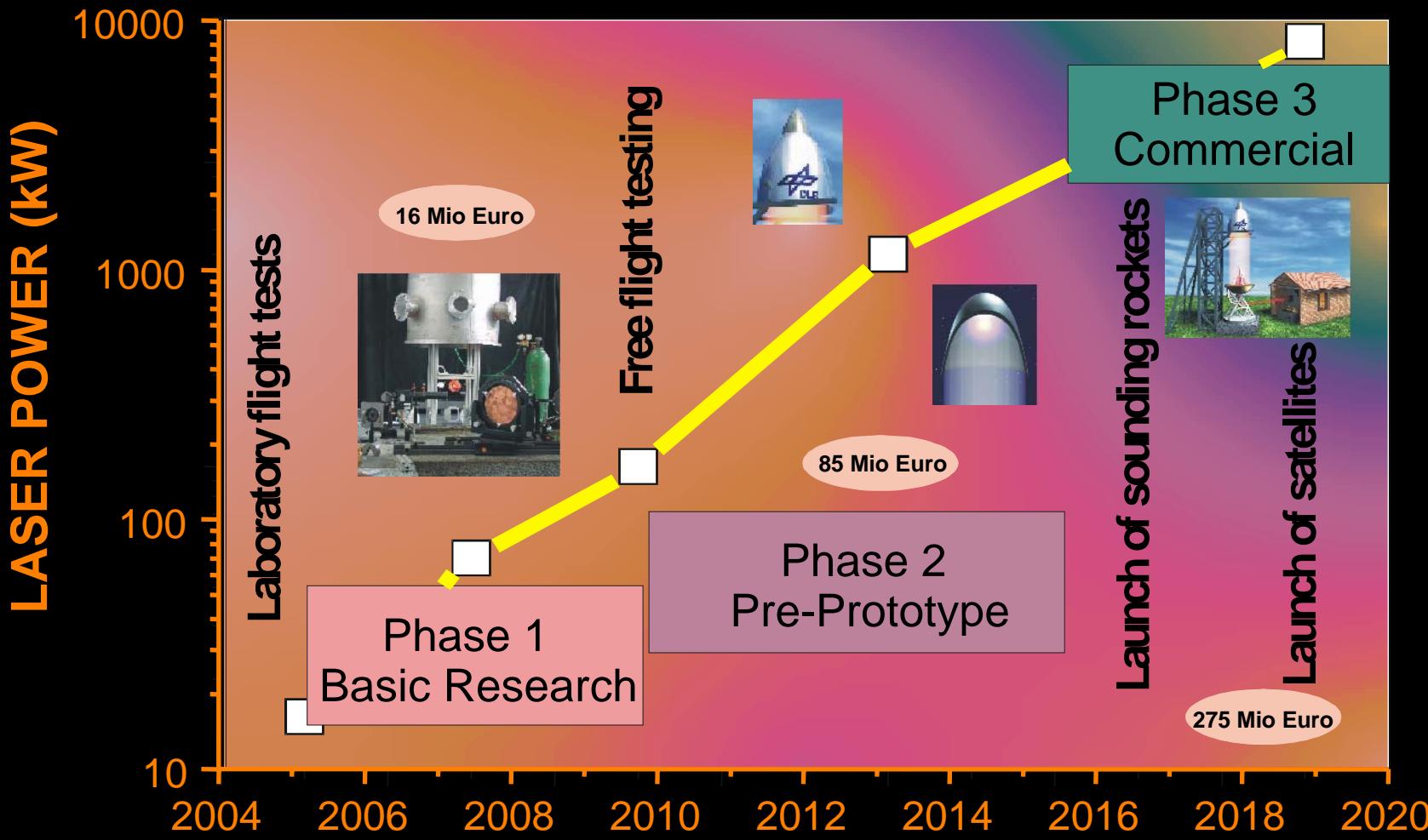


Air breathing propulsion possible to altitudes of about 30 km !

With Delrin in vacuum $v_{ex} = 2400 \pm 200$ m/s

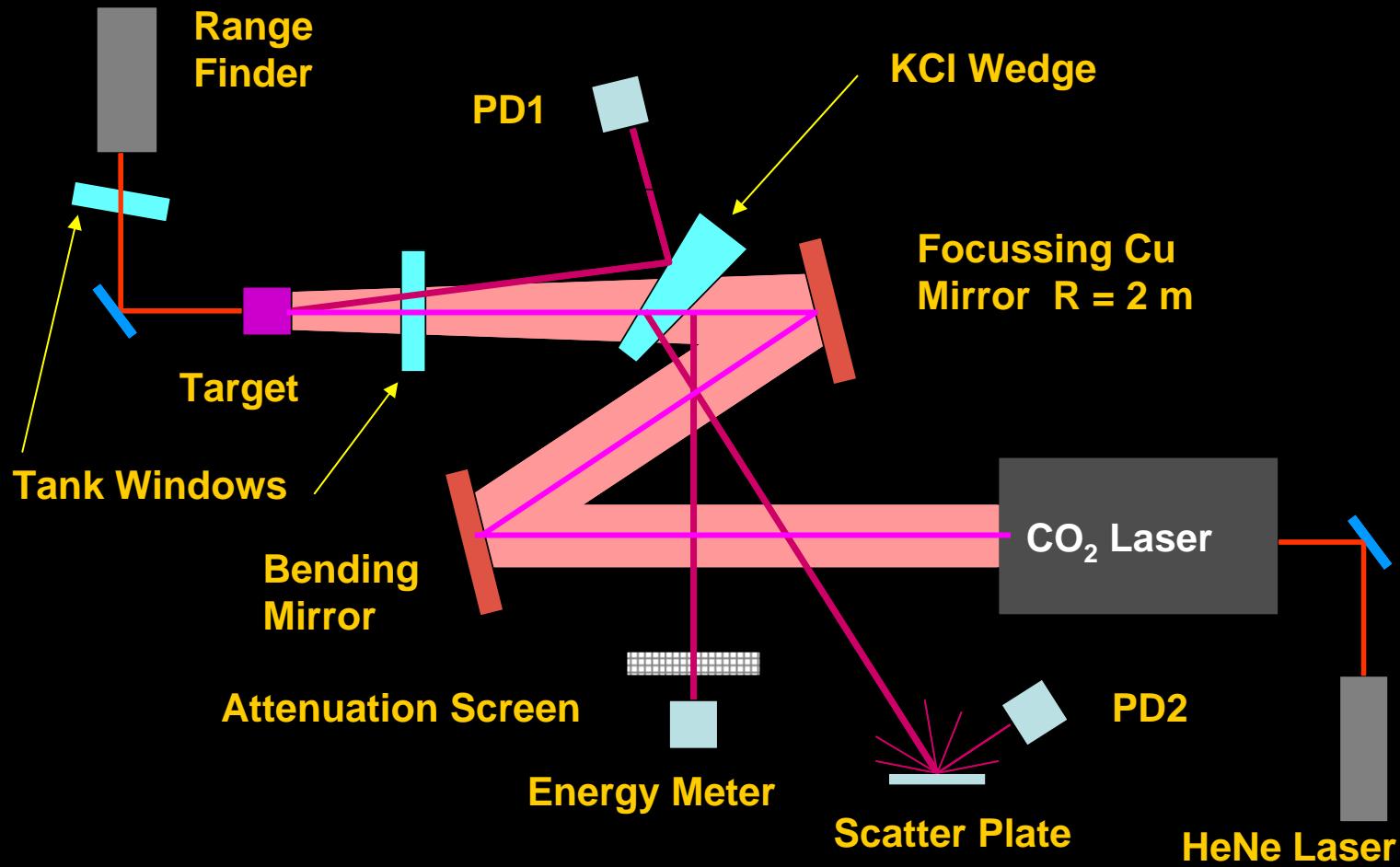


LASER LAUNCH SYSTEM DEVELOPMENT ROADMAP



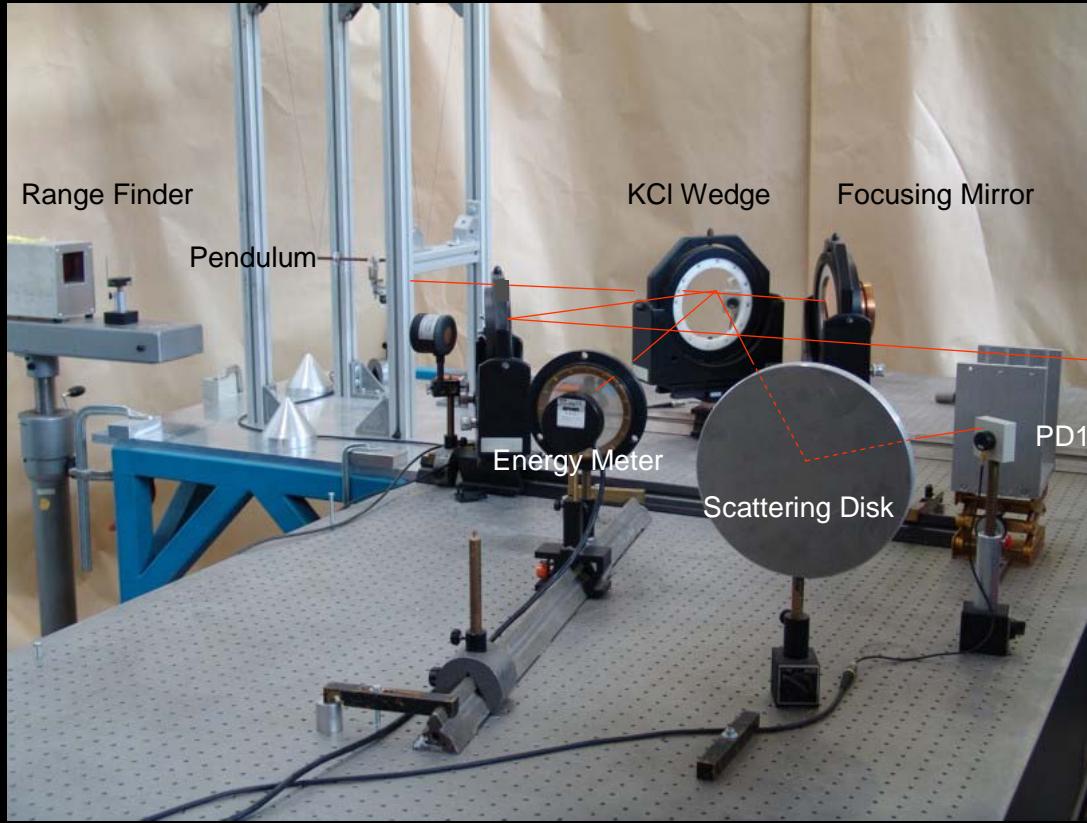


EXPERIMENTAL SETUP

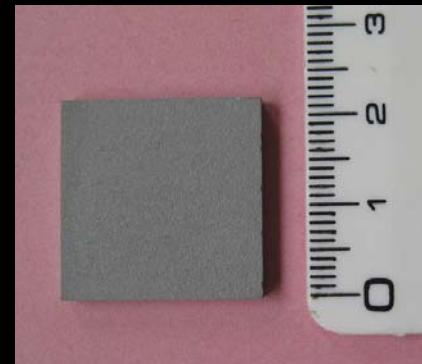
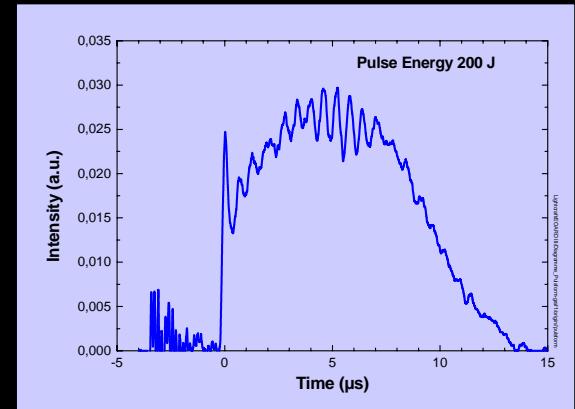




EXPERIMENTAL SETUP



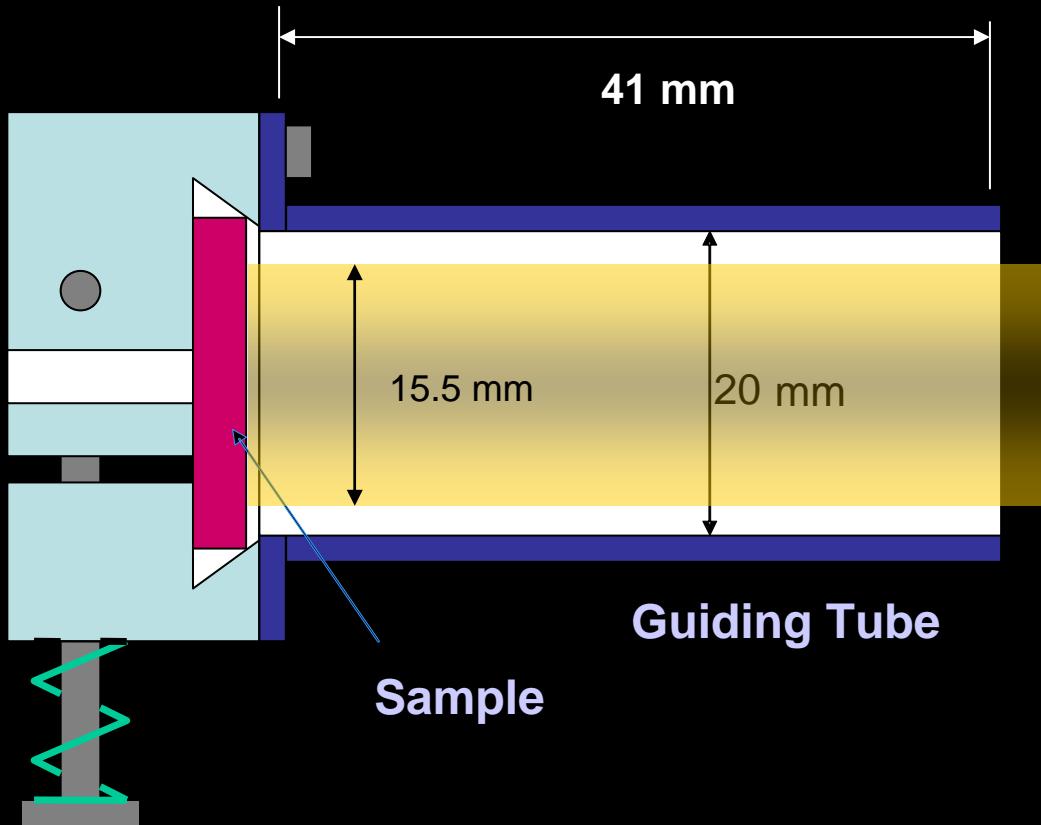
Laser Pulse Profile



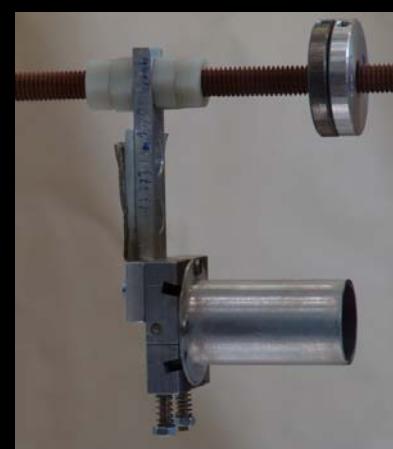
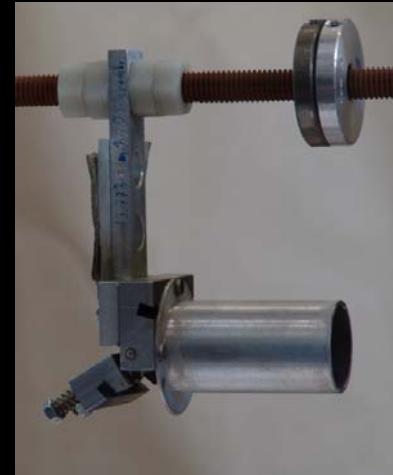
Sample



SAMPLE HOLDER



Guiding Tube for 1-D Expansion





SAMPLE FORMULATIONS

POM = PolyOxyMethylene = Polyacetal = *Delrin®*

POM + Al **0, 20, 40, 60 % by wt.**

Epoxy + Al **0, 3, 5, 10, 17, 30, 40, 50 % by wt.**

Epoxy + Mg **0, 3, 5, 10, 17, 30, 40 % by wt.**

Others: **Polybutadiene + Al, POM + Fe, POM + Ti**

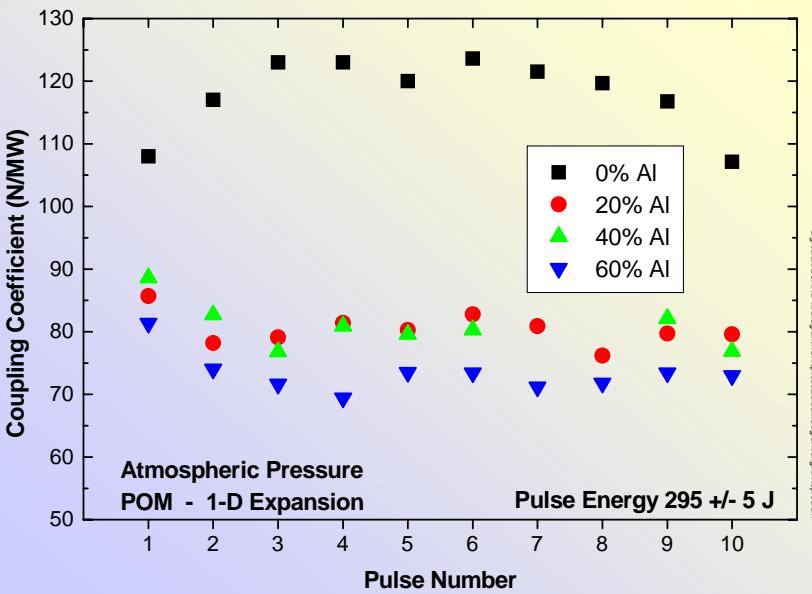


OUTLINE

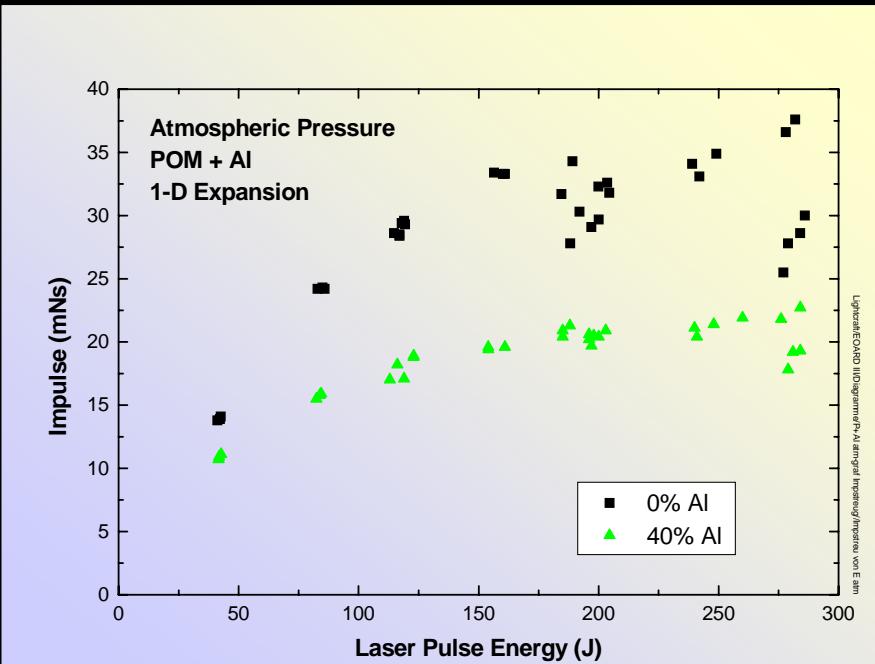
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REPRODUCIBILITY



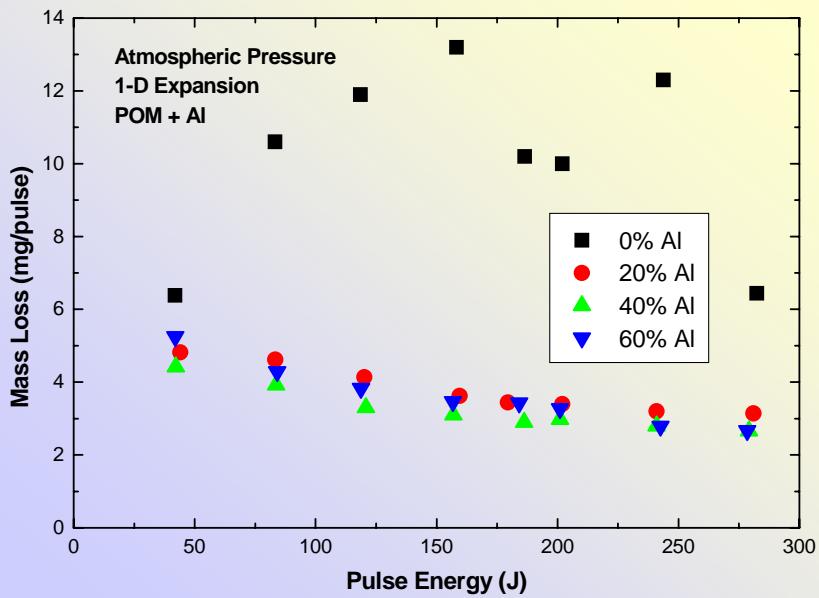
Shot to shot result on one sample



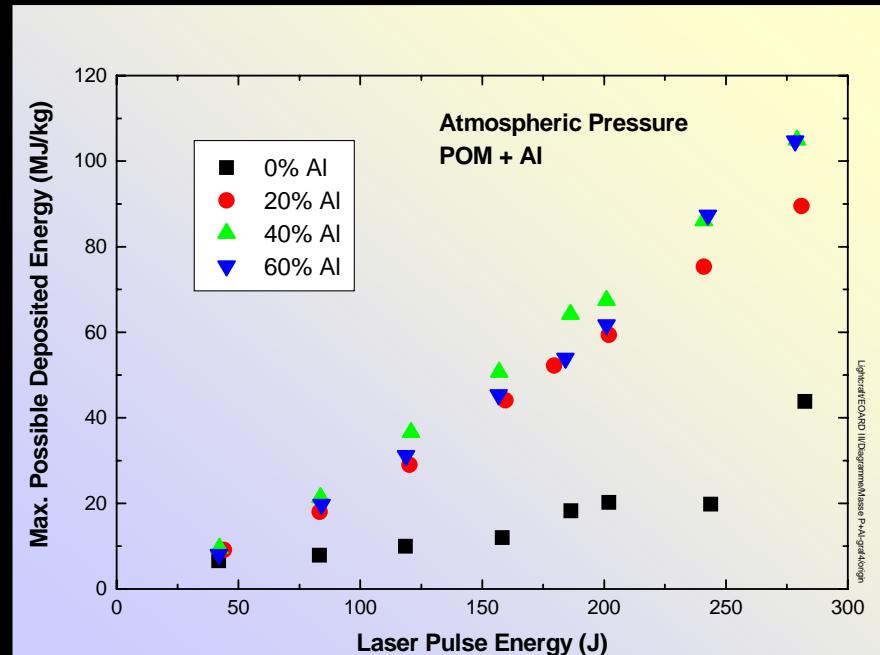
Scatter for individual shots



ABLATED MASS IN AIR



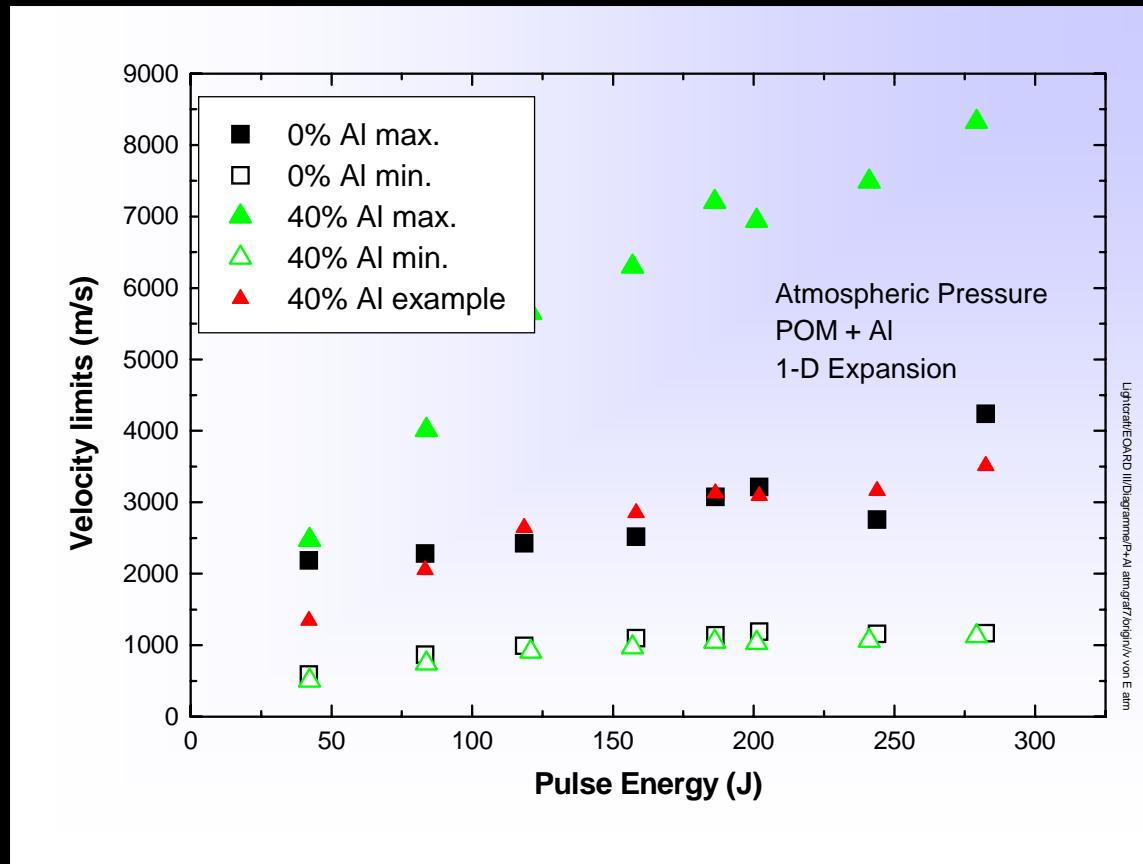
Ablated Mass vs. Pulse Energy



Apparent Deposited Energy
→ Upper limit



EXAMPLE: LIMITS TO THE VELOCITY



Upper Limit: 8500 m/s

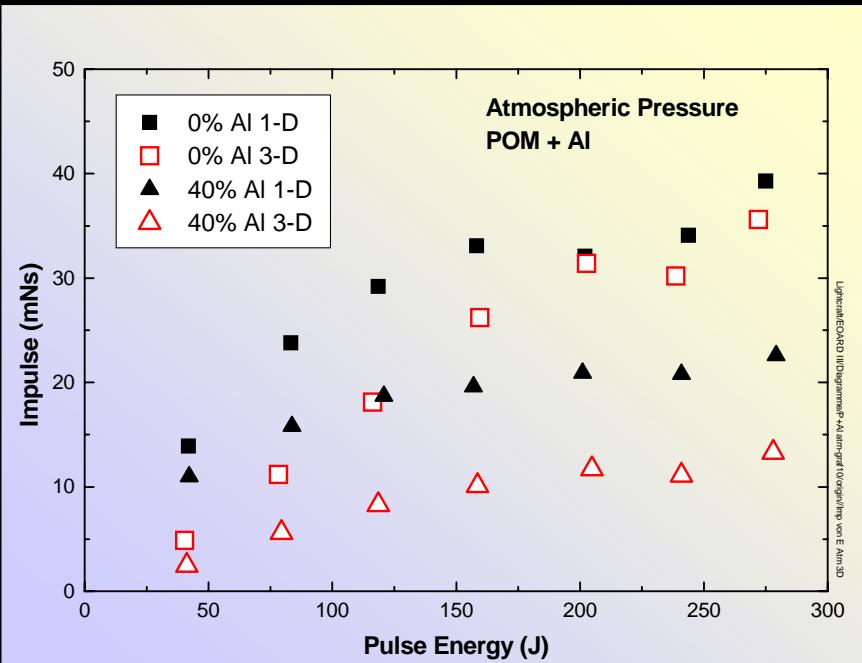
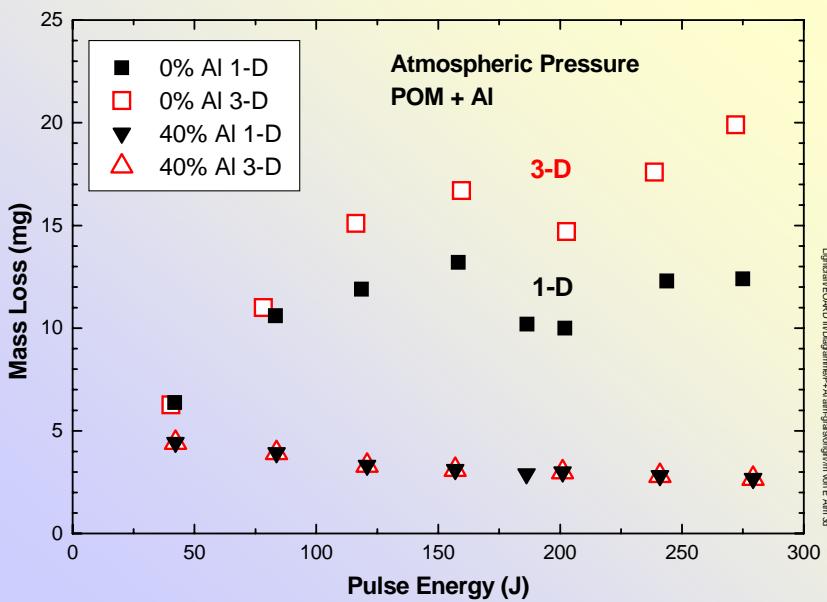
No air exhausted

Lower Limit: 1200 m/s

All air in tube exhausted



3-DIMENSIONAL EFFECTS

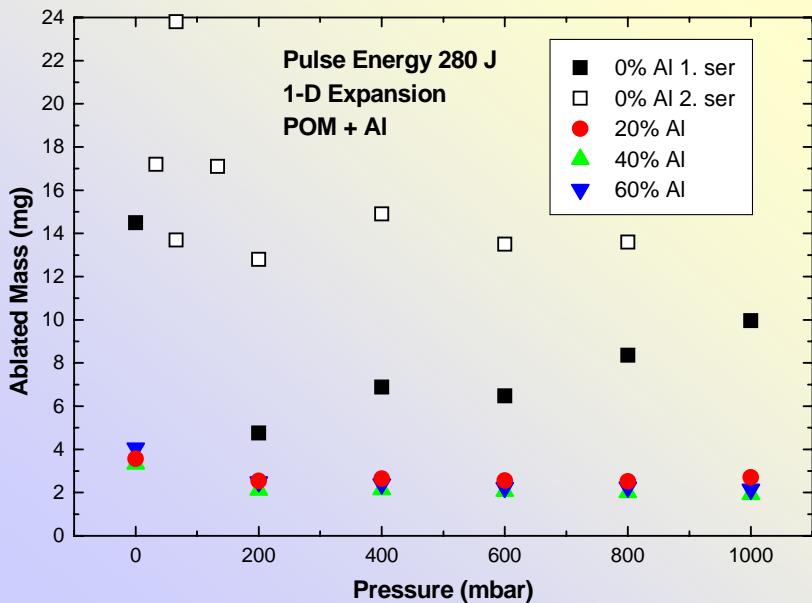


Mass Loss: 3-D vs. 1-D

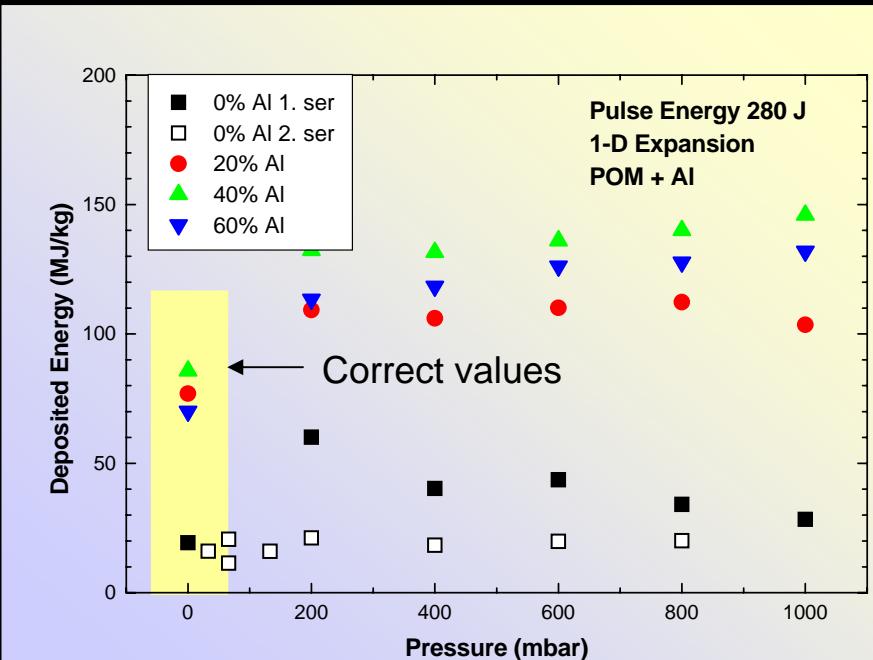
Impulse: 3-D vs. 1-D



REDUCED PRESSURE



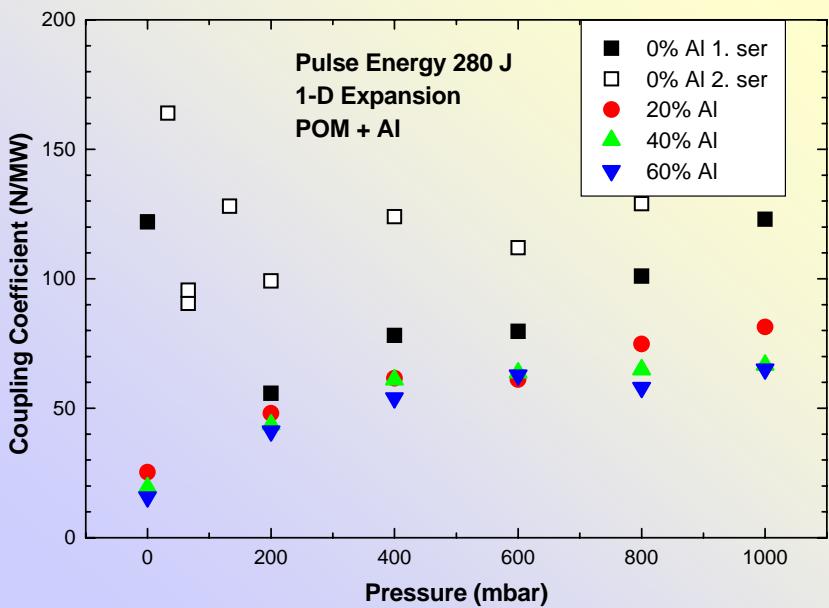
Ablated Mass vs. Pressure



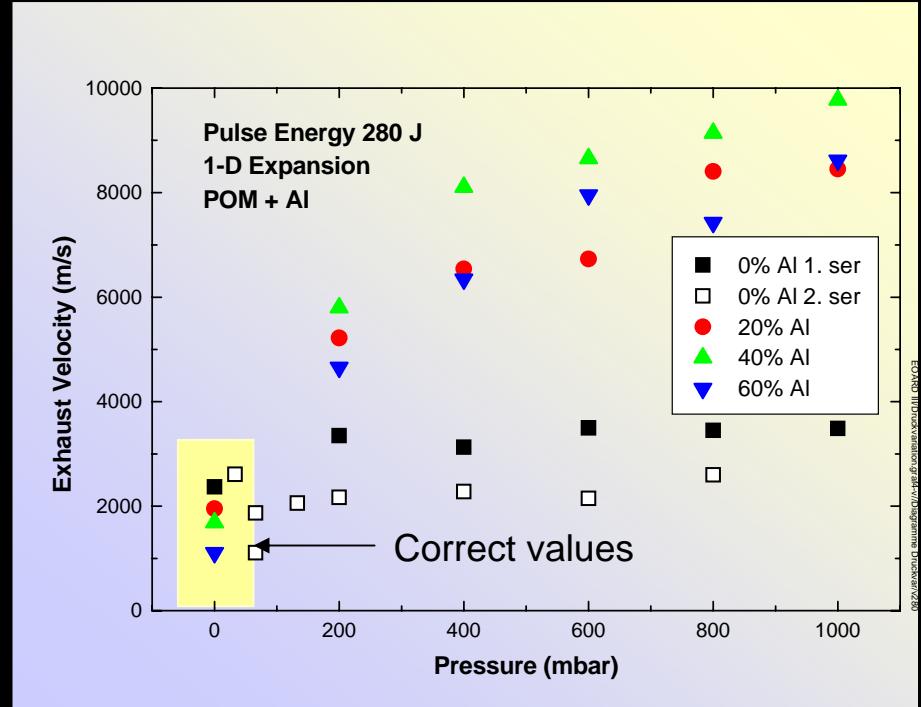
Apparent Deposited Energy
Correct only in vacuum



REDUCED PRESSURE



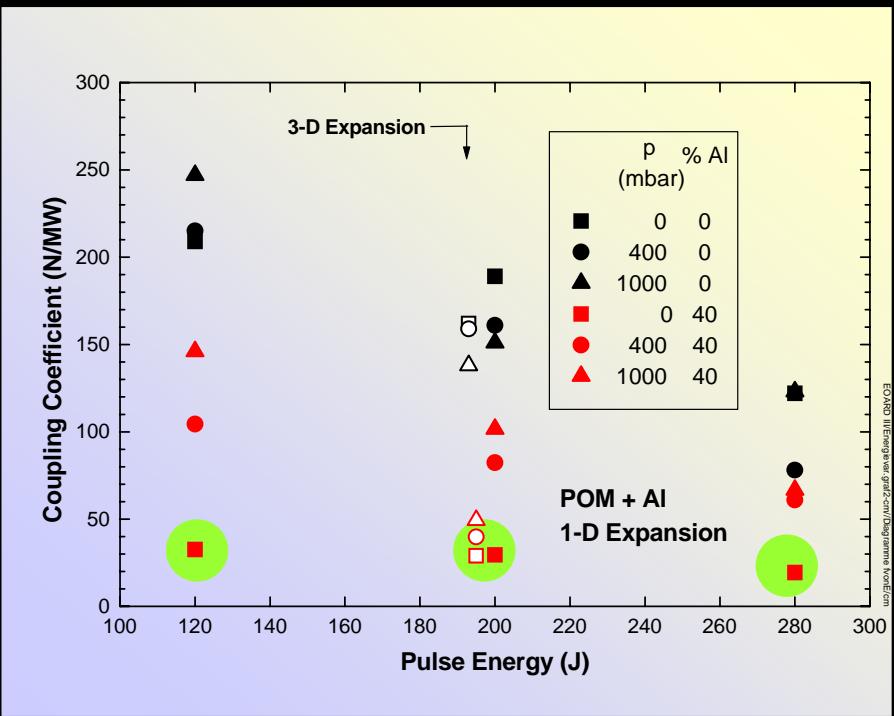
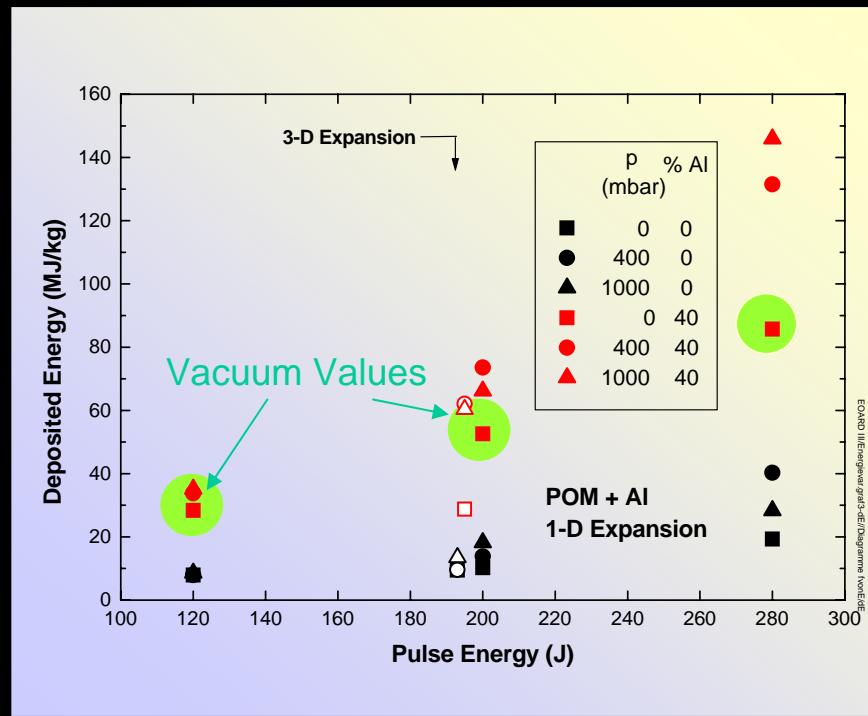
Coupling Coefficient vs. Pressure



Apparent Jet Velocity
Jet Efficiency in vacuum < 0.03



REDUCED PRESSURE

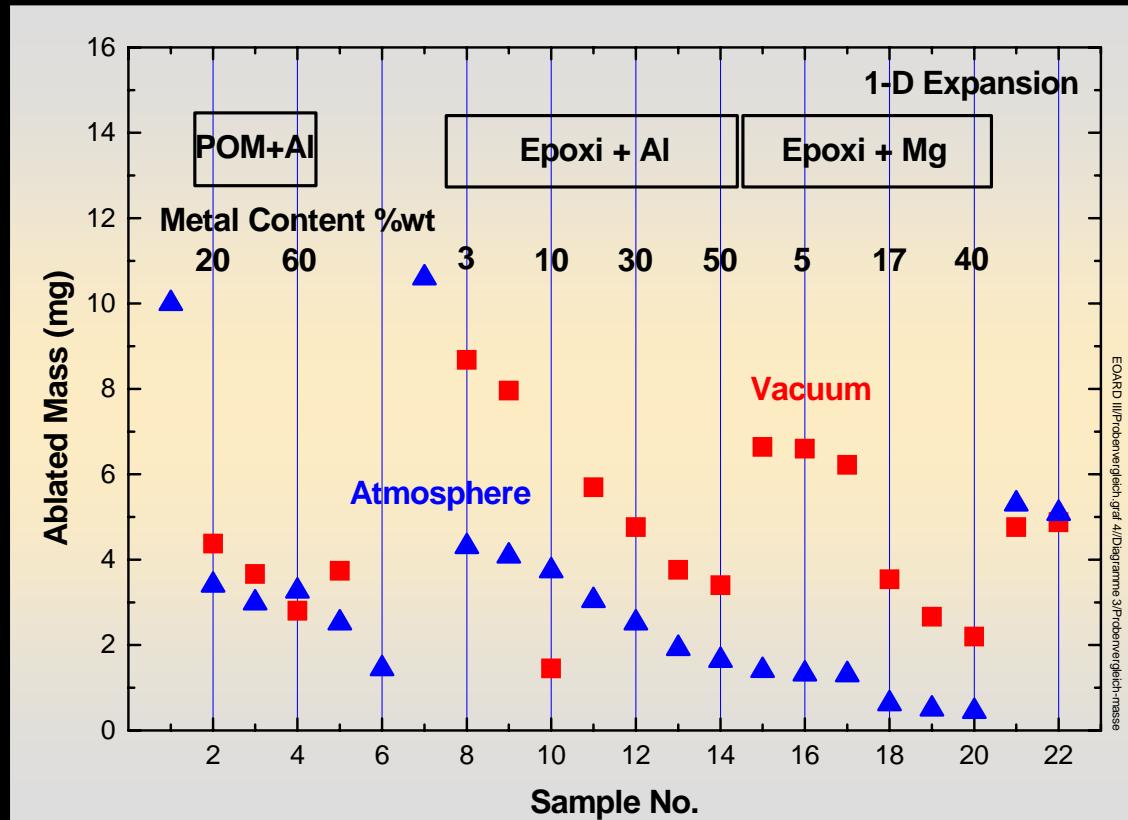


Deposited Energy vs. Pulse Energy

Coupling Coefficient vs. Pulse Energy



SAMPLE COMPARISONS - Ablated Mass



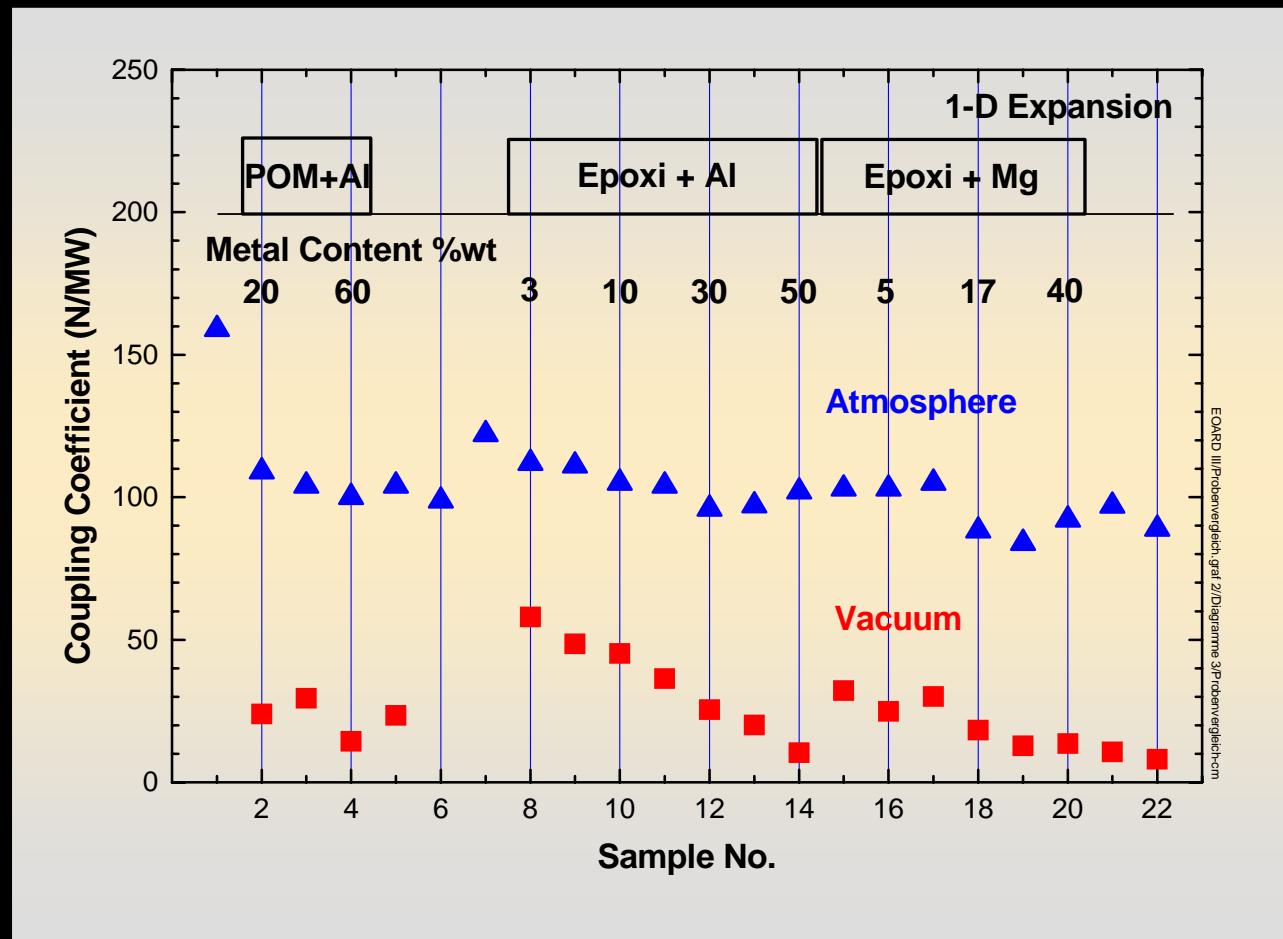
Pulse Energy
200 J

$$\text{In Vacuum: Deposited Energy} = \begin{cases} 50 - 70 \text{ MJ/kg} & \text{POM + AI} \\ 20 - 60 \text{ MJ/kg} & \text{Epoxy + AI} \\ 30 - 90 \text{ MJ/kg} & \text{Epoxy + Mg} \end{cases}$$



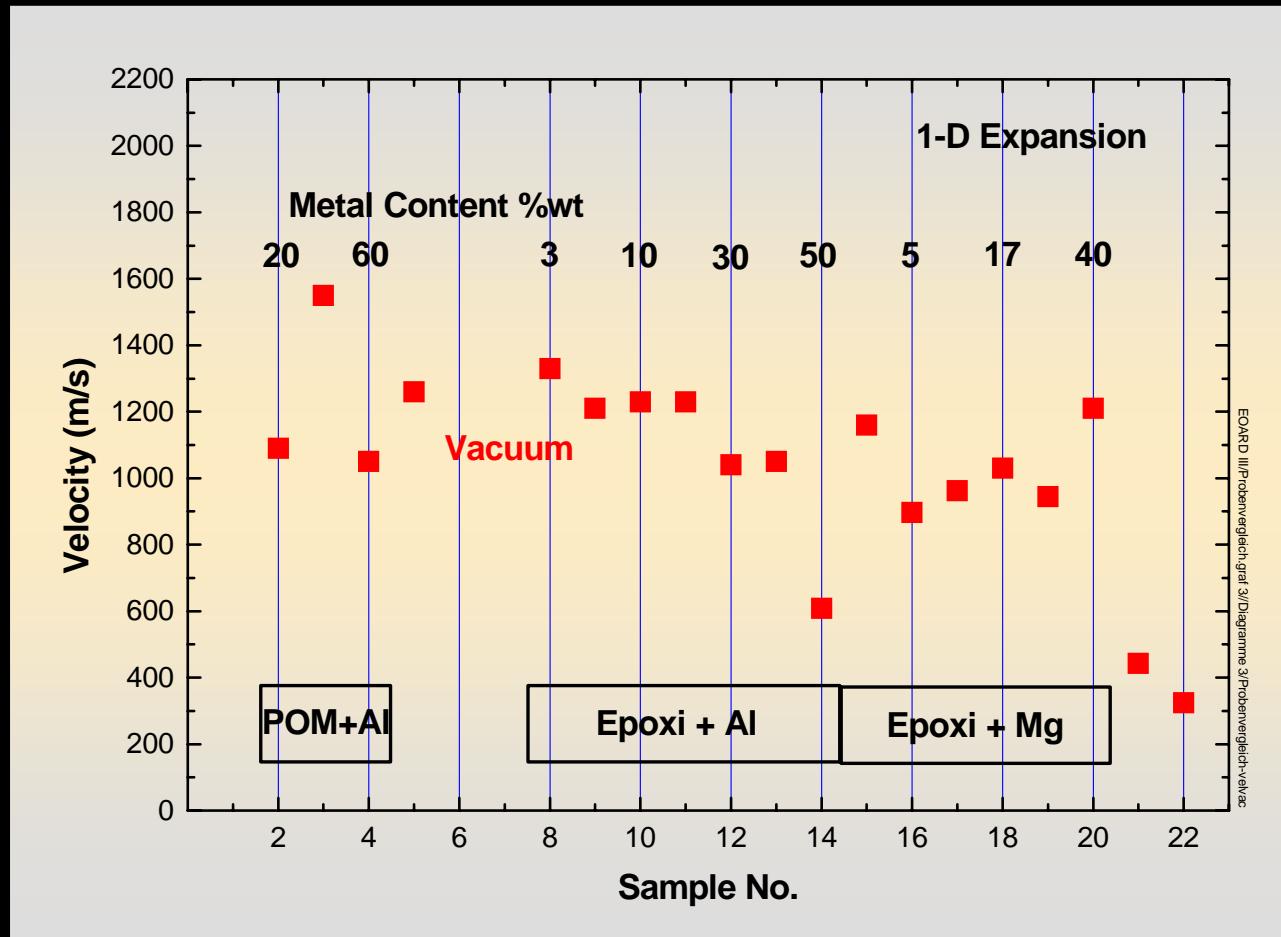
SAMPLE COMPARISONS - Coupling Coefficient

Pulse Energy
200 J



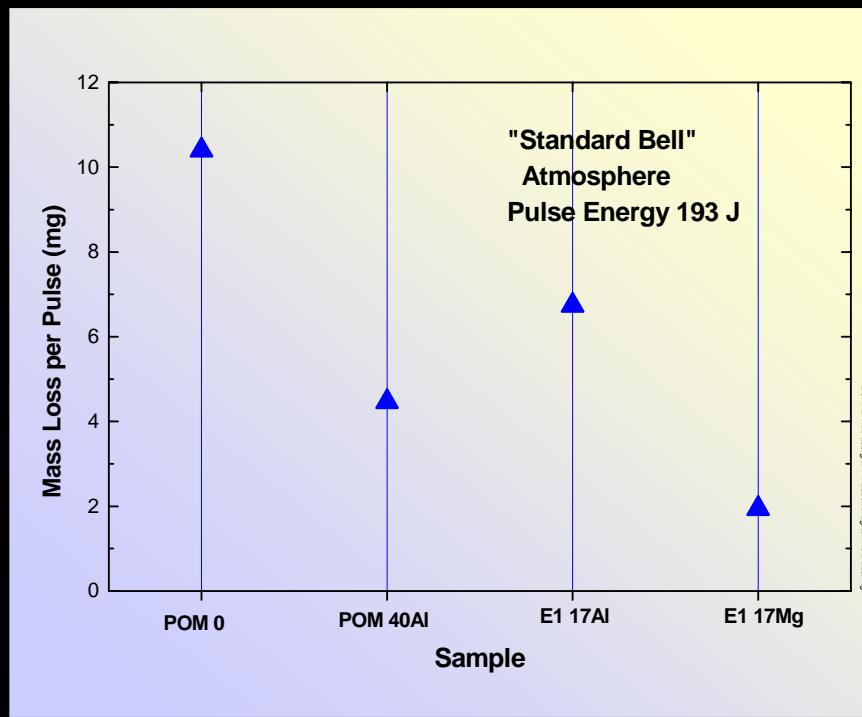


SAMPLE COMPARISONS - Jet Velocity

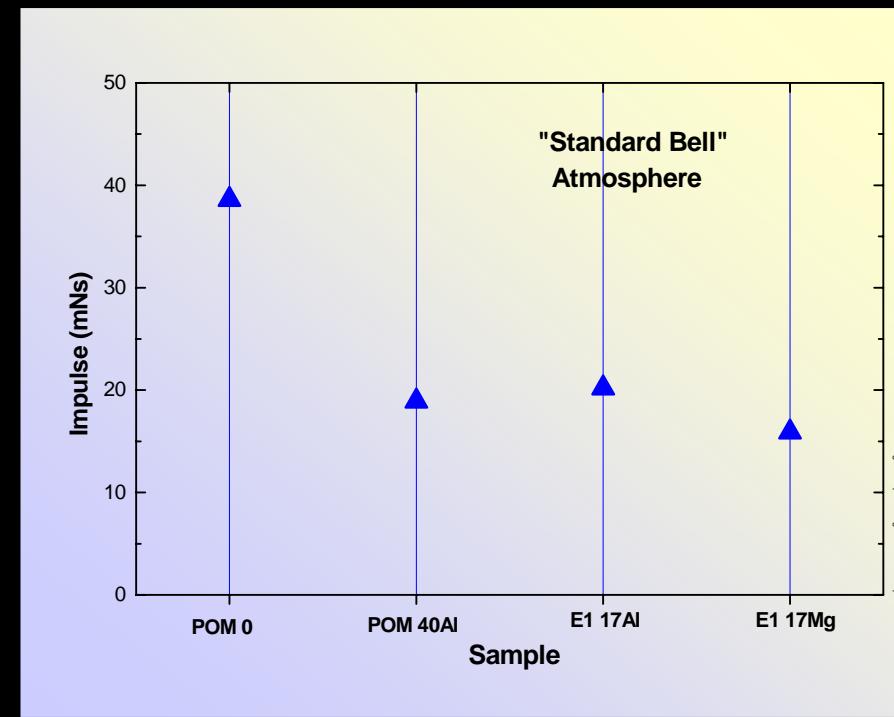




COMPARISON WITH LIGHT CONCENTRATING STRUCTURE ("BELL NOZZLE") IN AIR – 200 J



20 ... 50 MJ/kg 100 MJ/kg
Apparent Deposited Energy



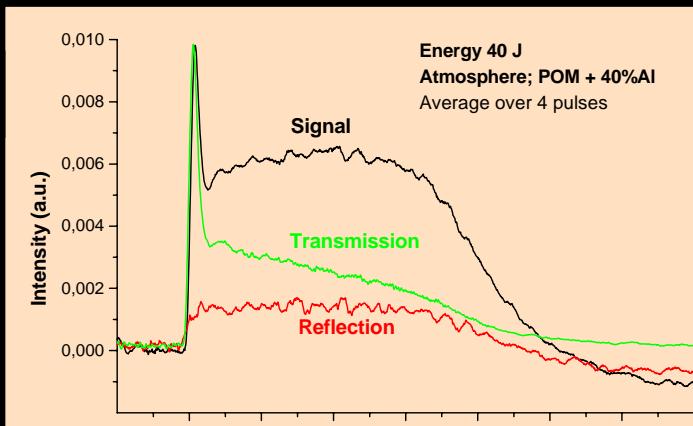
200 N/MW 100 N/MW
Coupling Coefficient



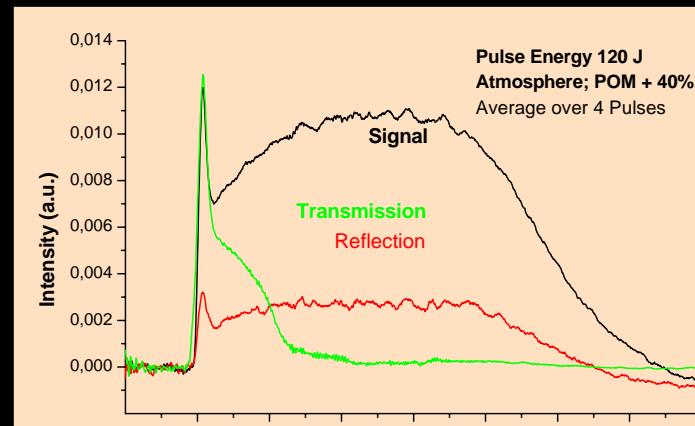
POWER PROFILES

POM + 40 % Al in air

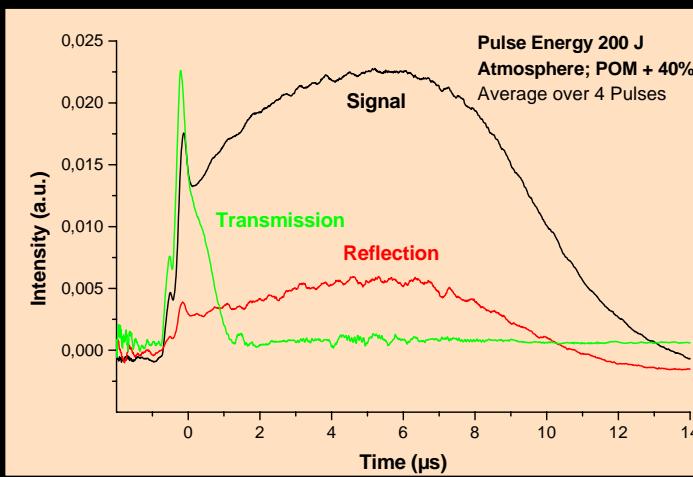
40 J



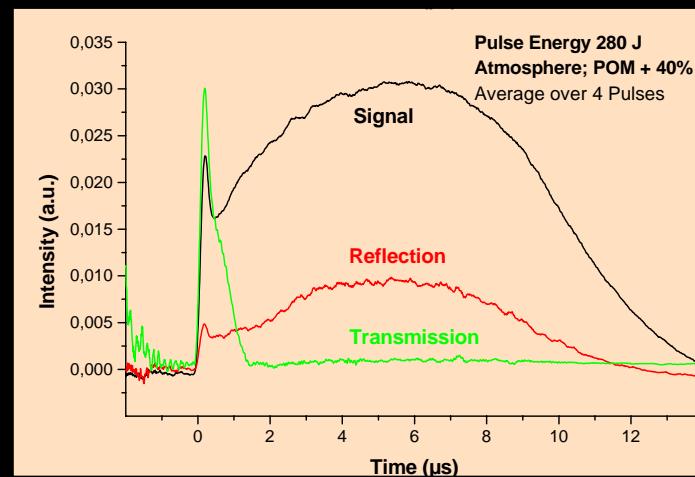
120 J



200 J



280 J





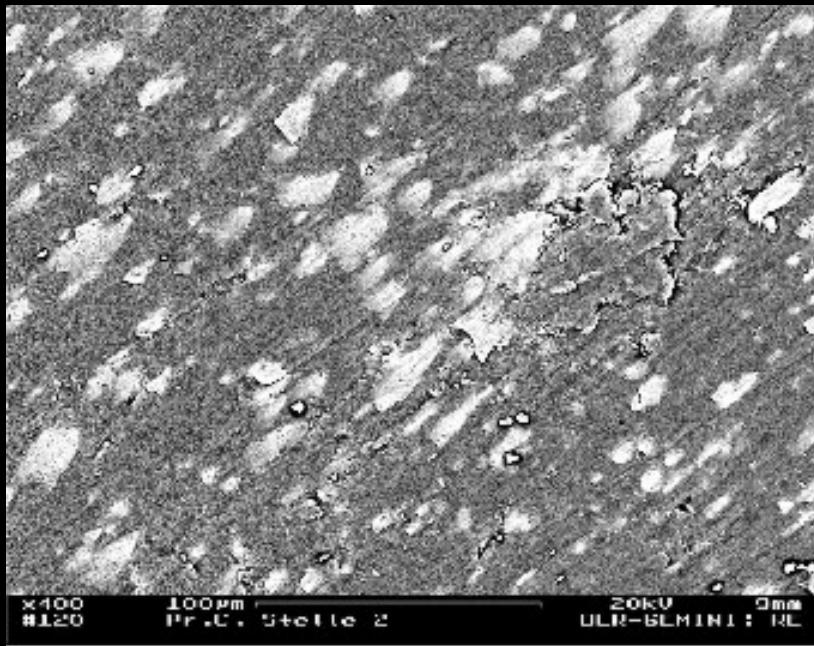
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ELECTRON MICROSCOPE PICTURES

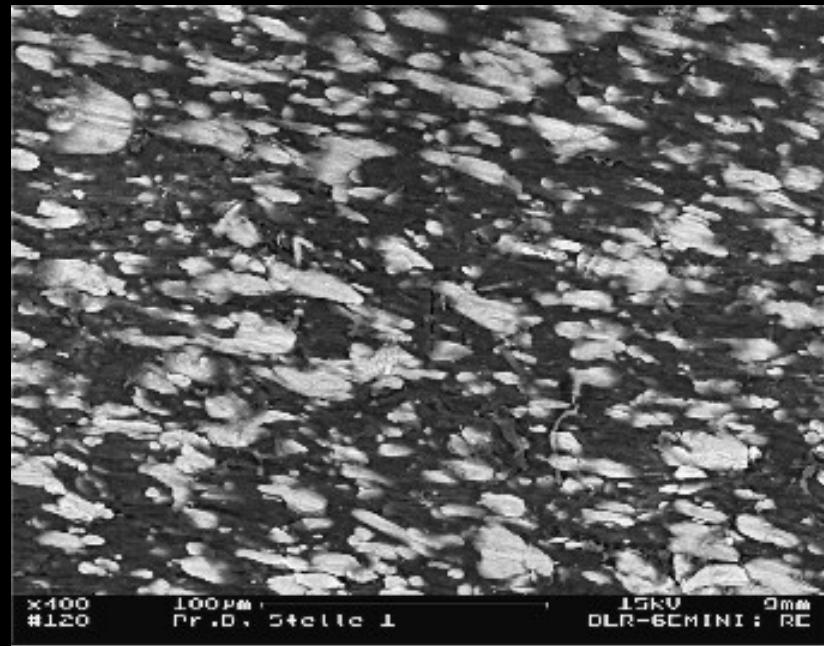
Before Laser Irradiation



POM + 20 % Al

400x

RE-Mode

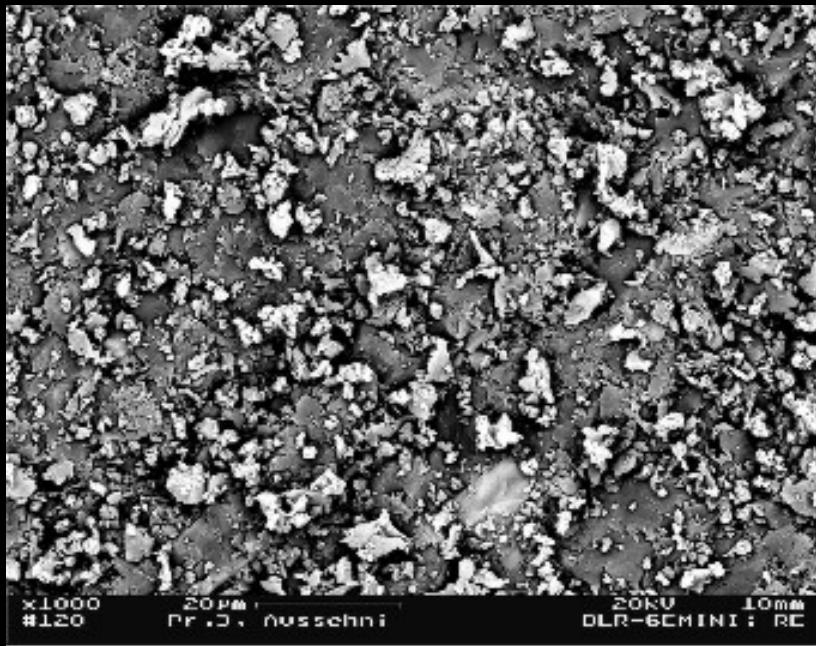


400x



ELECTRON MICROSCOPE PICTURES

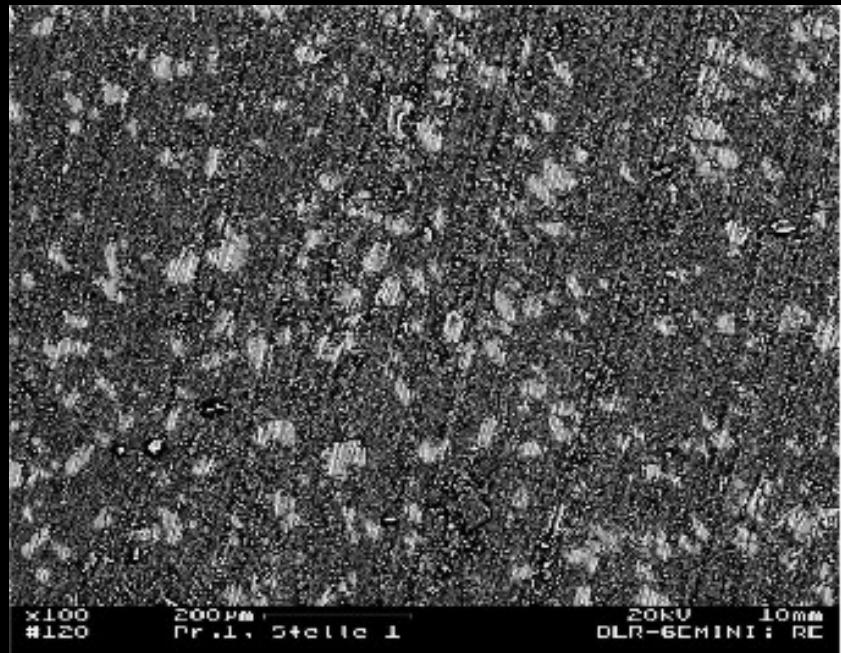
Before Laser Irradiation



Epoxy + 17% Al

1000x

RE-Mode



Epoxy + 17% Mg

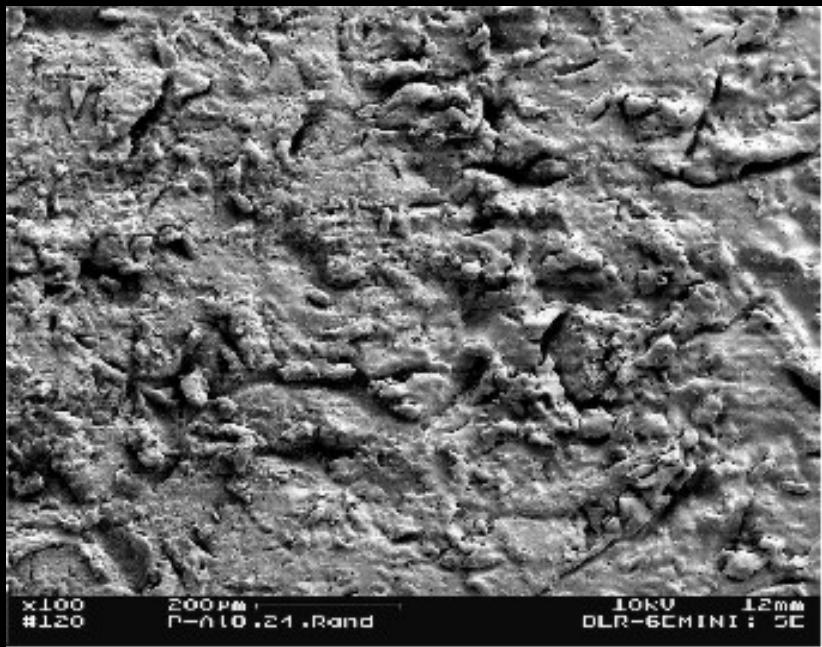
100x



ELECTRON MICROSCOPE PICTURES

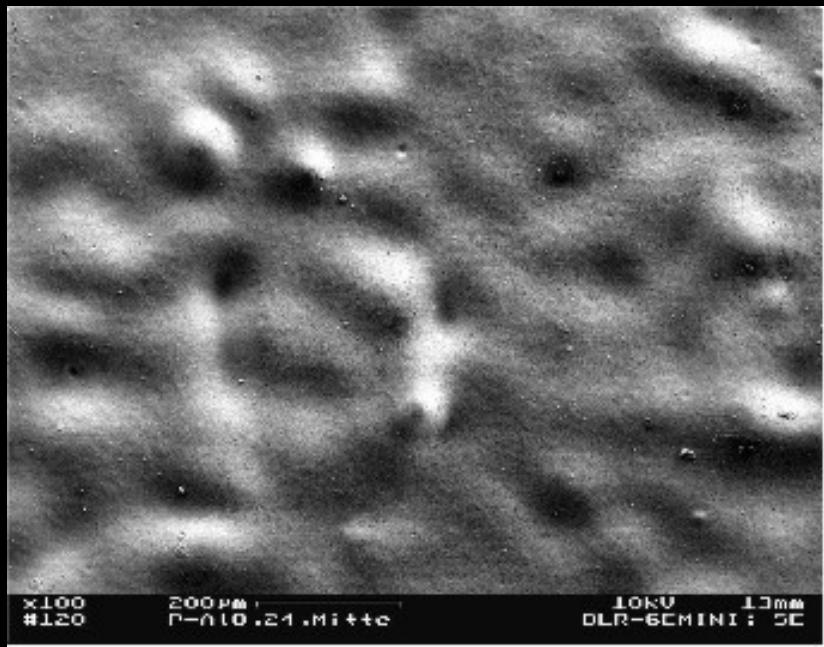
After Laser Irradiation

SE-Mode



POM – edge

100x



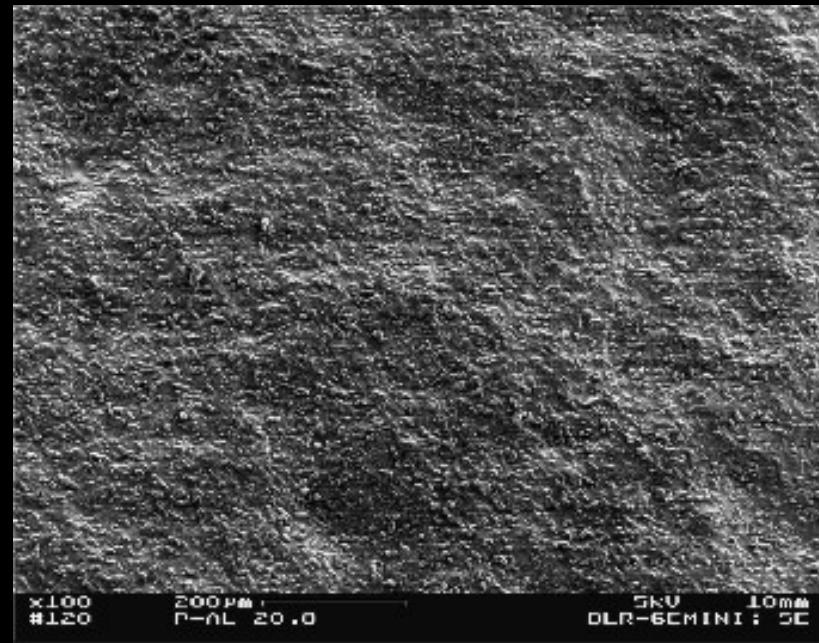
POM - center

100x



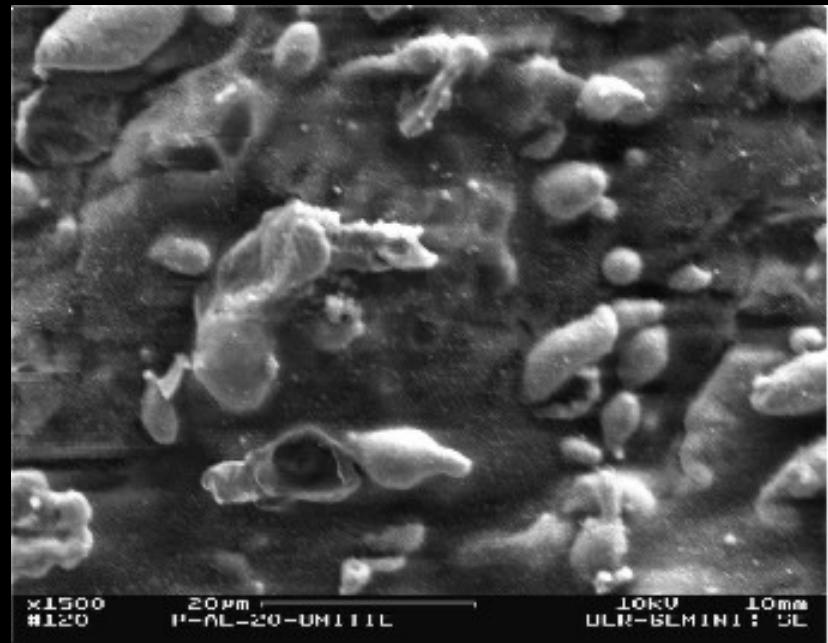
ELECTRON MICROSCOPE PICTURES

After Laser Irradiation



POM + 20 % Al - center 100x

SE-Mode 200 J vacuum



POM + 40 % Al 1500x

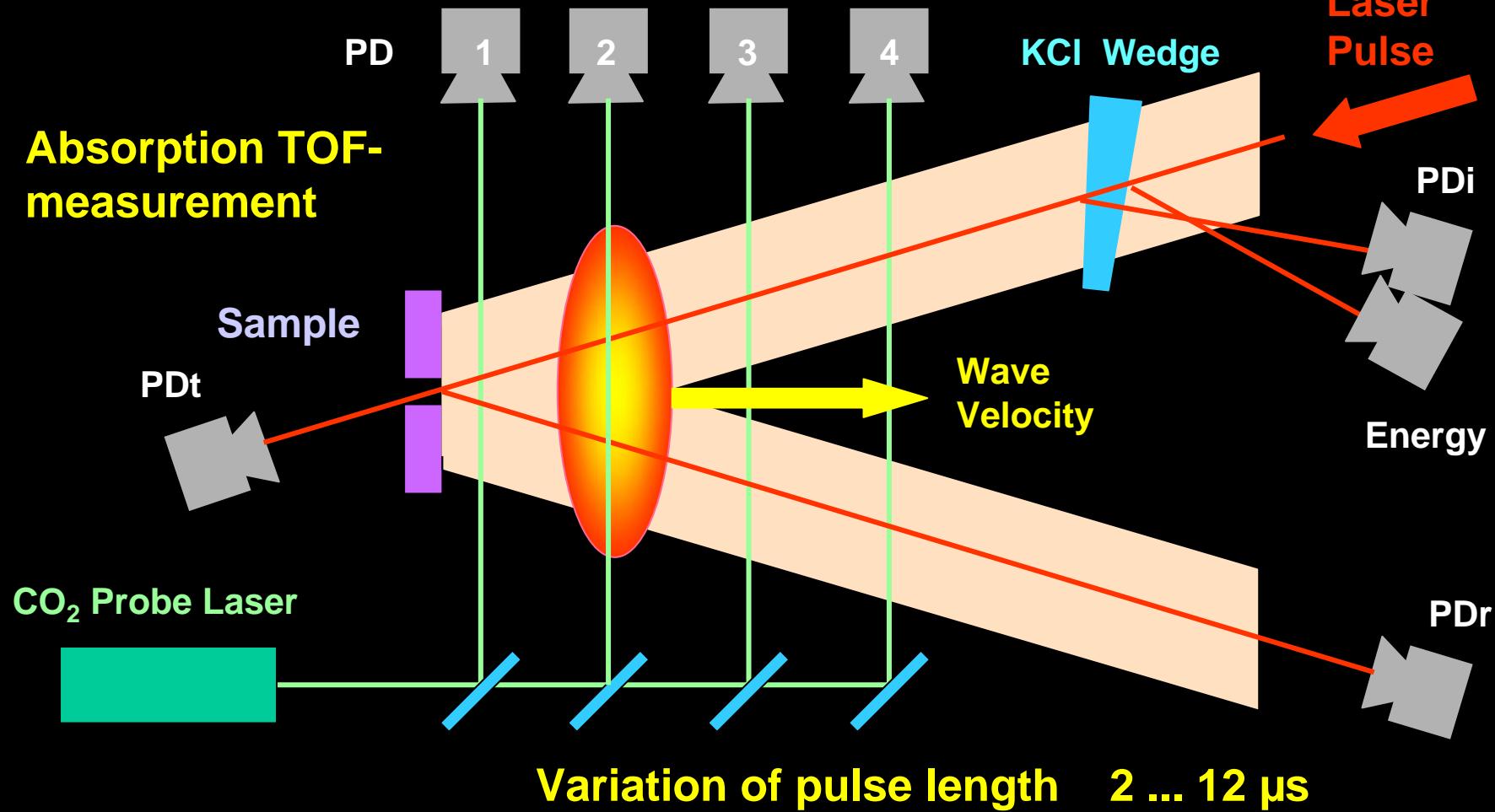


CONCLUSIONS

- Goals for $I_s = 800$ s not met
- In air → accelerated air fraction unknown
 → all related values are wrong
- In vacuum → deposited energy goes up with increasing metal fraction, but coupling coefficient decreases
- Strong evidence for large energy loss in a decoupled laser absorption wave
- Nature and characteristics of absorption wave need investigation
- Can shorter pulse lengths help prevent decoupling?



PROPOSAL FOR NEW EXPERIMENTS





POM after laser irradiation 3000x